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# THE DEEPWATER SHRIMP FISHERY OF THE NORTHERN MARIANA ISLANDS

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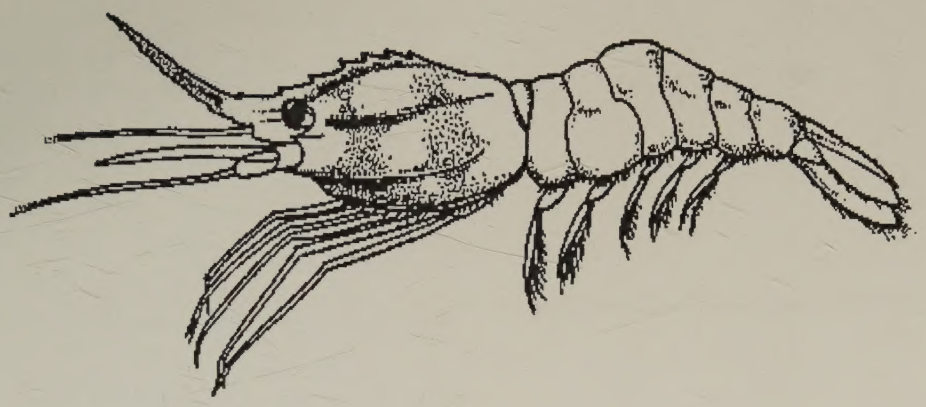
Southwest Fisheries Science Center
Administrative Report H-97-10

# THE DEEPWATER SHRIMP FISHERY OF THE NORTHERN MARIANA ISLANDS



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## PREFACE

This report was prepared when its author was a fisheries biologist with the Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife. It represents the first time that a technical report prepared by an island scientist has been made available as a National Marine Fisheries Service (NMFS) Southwest Fisheries Science Center administrative report. It is reported as provided by the author. Written permission to publish these data is on file at the Honolulu Laboratory. This report was prepared with the assistance of the Western Pacific Fishery Information Network (WPacFIN). WPacFIN is a collaborative relationship between the NMFS and the island fisheries agencies of American Samoa, Guam, Hawaii, and the Northern Mariana Islands, as well as the Western Pacific Regional Fishery Management Council.

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Data collection and processing was carried out by Joseph Ostazeski, Michael S. Trianni and other DFW personnel. This report was prepared by Joseph Ostazeski.

## SUMMARY

Harvesting of the smooth nylon shrimp, *Heterocarpus laevigatus*, in the Northern Mariana Islands began in May of 1994 by Laulau Bay Fisheries, Inc. (LBF) and continues intermittently by the JQC Fishing Company (JQC). LBF fished a total of 193 days mostly on grounds around Saipan and Tinian, landing a calculated total of 8,125 kg of whole *H. laevigatus*. The overall catch-per-unit-effort was 1.14 kg/trap-night. LBF left the fishery in June of 1995, citing gear loss as the primary reason for discontinuing. Their rate of gear loss was 3.5% per day. JQC entered the fishery in December of 1995, with total landings of *H. laevigatus* as of March, 1996 estimated to be 4,035 kg from 20 days of fishing in areas near Rota, Aguijan, and Saipan. The overall catch rate for the JQC trapping operation is 0.87 kg/trap-night. The LBF catch composition was 97.5% *H. laevigatus* by number, with a mean carapace length of 45.7mm. Of *H. laevigatus* caught by LBF, 78.4% of females and 97.8% of males had reached that size at maturity. Females outnumbered males nearly 3 to 1. The catch rate presented here indicate that the fishery has yet to be fully exploited and there is room for expansion. However, the high costs of fishing in deep water may be more limiting than sustainable yield.

## INTRODUCTION

There has been interest in harvesting deepwater pandalid shrimp of the genus *Heterocarpus* since the early 1970s when initial resource surveys were conducted in the Hawaiian Islands (Clarke 1972; Struhsaker and Aasted 1974). *Heterocarpus* shrimp have since been found in locations off virtually all of the Pacific islands that have been surveyed, including the Northern Mariana Islands and Guam (Fig. 1) (Moffitt 1983; Moffitt and Polovina 1987; and Wilder 1977), Western Samoa (King 1980a), New Hebrides (King 1980b) Tonga (King 1981a), Vanuatu (King 1981c), the Northern Gilbert Islands (Preston 1988), and in Palau (Saunders and Hastie 1989). It is believed that these shrimp represent a large relatively unexploited resource that should prove valuable to Pacific island nations and states.

Of the 10 species of "nylon" shrimp in the genus *Heterocarpus* (Holthuis, 1980), 8 species are present in the Northern Mariana Islands (Moffitt and Polovina 1987), of which *H. ensifer* and *H. laevigatus* have been identified as offering the greatest commercial potential. Wilder (1977) conducted the first the studies of deepwater shrimp in the Mariana Archipelago in the waters surrounding Guam, which indicated a potential annual yield of 2 to 3 metric tons (t) of *H. ensifer* and *H. laevigatus*. Moffitt (1983) went on to identify *H. ensifer, H. laevigatus* and also *H. longirostris* as species present in Saipan and Tinian waters in great enough abundance to be of possible interest to commercial fishing. Further assessment activity by Moffitt and Polovina (1987) suggested an annual yield of 162 t/year of *H. laevigatus* for the entire archipelago. The yield breakdown for the fishing grounds around the islands of Saipan and Tinian was projected at over 70 t/year. Although there have been some intermittent attempts at harvesting *Heterocarpus* in Guam, these ventures have been small scale and short-lived (Gerry Davis, personal comm). Nevertheless, these projections along with limited commercial success of deep-sea shrimp fishing operations in Hawaii (Western Pacific Regional Fishery Management Council 1984; Tagami and Barrows 1988) encouraged the entry of a fishing company targeting *H. laevigatus* to begin fishing in waters surrounding Saipan on a trial basis in May 1994. Laulau Bay Fisheries, Inc. (LBF) continued to fish through June 1995 when they stopped fishing operations. Another venture, the JQC Fishing Company (JQC), entered the fishery in December 1995 and has been active through March, 1996. The primary purpose of this study is to document the shrimping operations of Laulau Bay Fisheries, Inc. and the JQC Fishing Company and examine some biological parameters of the target species, *H. laevigatus*.

## METHODS

### Fishing Gear and Methods of Laulau Bay Fisheries, Inc.

Harvesting of deepwater shrimp by Laulau Bay Fisheries, Inc. began in May of 1994 and continued into August 1994 utilizing the Bluewater Hunter which is a 30-ft fiberglass Radon-hulled boat with twin outdrive Mercury cruiser 230-hp engines. The boat was outfitted with a depth sounder to 400 fathoms, GPS plotter, and Osco pinch hauler. The fuel capacity of the

vessel was 450 gallons, and the vessel's consumption rate was 5 gallons/hour with an 18-knot cruising speed. For this initial experimental period fishing was mostly restricted to areas around Saipan, with a high concentration of effort in Laulau Bay and the Marpi reef area. Fishing continued in November of 1994 using the Marlin II, a 45-ft aluminum Hamilton Marine hull Australian boat, powered by twin Volvo 500-hp engines (Fig. 2). The electronics used were a JCR 2000 depth sounder to 900 fathoms and a Siltex GPS plotter. The boat was fitted with a Hamilton Engineer pinch hauler with Nigata hydraulics. The fuel capacity of the vessel was 400 gallons and the consumption rate was 7 gallons/hour with a cruising speed of 18 knots. Fishing activity ranged in location from Zealandia Bank north of Sarigan to areas around Aguijan, but were concentrated around the northwestern aspect of Saipan (Fig. 1). The Department of Fish and Wildlife (DFW) monitored the fishing operation from February 1995 through June 1995 when trapping stopped.

The standard fishing gear used consisted of strings of oval plastic Fathom Plus traps (Figs. 3 and 4) attached to an 11-mm ground line with approximately 10-m separating traps. The traps used were of molded black plastic approximately 100-cm long, 80-cm wide, and 35-m high. The least inside mesh size dimension was about 18-mm. The traps were hinged down the middle on the bottom and had twin entry cones with mouth dimensions of 85-mm high by 55-mm long, which were offset on either side of the short axis. Corresponding plastic mesh bait tubes were stood vertically and were situated opposite to the entrance cones inside the traps. Individual traps were weighted with approximately 7 kg of lead or reinforcing bar fastened along the hinged bottom. Traps were attached to the ground line with a clip on the end of two 40-cm lengths of 11-mm rope forming a bridle which connected to the traps at four points on one end of the long axis of the trap (Fig. 4). The ground line connecting the traps and the surface line connecting the ground line to the surface buoys were of 11-mm polypropylene line. The ground and surface lines were anchored using three links of 2½-in stud length chain weighing approximately 20 kg. Traps were baited with about 0.7 kg of frozen Pacific mackerel, *Scomber japonicus*, which was cut in large cross sections and placed in the bait tubes.

During the study the number of traps used fluctuated from a maximum of 40 to a low of 3 per string. The number of traps set per string averaged 12.7. The usual protocol was to use a depth sounder to run a transect to determine the depth and suitability of the bottom profile prior to the deployment of a string. After locating a suitable site with a target depth of around 600-650 m, a string of traps was deployed one trap at a time off the stern while the vessel was running. Soak times were generally 16-24 hours, but sometimes extended to 40-48 hours when circumstances prevented prompt retrieval of gear. The gear was hauled on arrival the following day using a hydraulic winch with the hauled rope flayed down into a large plywood bin stationed below the winch. Trap spacing on the ground line and hauling time were such that the contents of the traps could be emptied and the trap re-baited before the next trap in the string was brought to the surface. Shrimp were immediately put on ice and kept in large coolers from 6-48 hours, more often 6-12 hours, before being brought to market.

From February 1995 through June 1995 weekly sampling was conducted either in port or at sea where samples of the catches of individual strings were examined. A minimum

volumetric sample of five liters or approximately 50 shrimp were examined per string with multiple samples examined if time permitted. Species determinations were made following the key in King (1986) (Appendix 1). Sex was determined from the shape of the endopods of the first pair of pleopods; in males the shape is more club-like than the females which is more elongated (Appendix 2 (King and Moffit 1984)). Gravidness in females was easily determined by examining the pleopods for the presence of eggs. Carapace length was recorded by measuring the carapace from the posterior margin of the eye orbit to the posterior median edge of the cephalothorax. Other information recorded on sample days was the precise location and depth at which the string was set and the approximate catch weight per string. Depth was read from the depth sounder when the marker buoy anchor was deployed or retrieved. Additional information for fishing location, depth, fishing effort, catch, and gear loss was obtained from the vessel log books for non-sample days. Total catch data was obtained from the buyer for the period of November 1994 through May 1995 when that single company was marketing all of the catch.

## Fishing Gear and Methods of the JQC Fishing Company

A subsequent venture by the JQC Fishing Company to target *Heterocarpus* shrimp began in December of 1995 and continues intermittently. The vessel used is the 110-ft, 150-t Kyuishu pair trawler, JQC I, powered by a 1100-hp engine. The JQC I is fitted with a Marko JO 117 line hauler, depth sounder and GPS plotter. This fishing operation also uses strings of low volume traps; however, the trap design differs considerably from those utilized by the first fishing operation. The traps utilized by the JQC I are of Japanese design originally for a crab fishery in Japan and feature a lightweight plastic-coated 10-mm diameter steel bottom hoop with four 8-mm diameter steel supports arcing from the bottom to create an upside-down bowl shape (Figs. 5 and 6). The overall trap dimensions are 80-cm base diameter by 30-cm high. This frame is covered with nylon netting that has an inside stretched eye diameter of 28-mm. The relaxed inside mesh width is approximately 16-mm; however, this dimension is not very uniform because stretching of the netting over the frame often decreases the width. Traps have a single plastic entrance cone with an opening diameter of 10-cm located on the top. Twin bait pouches of the same nylon mesh are situated on either side of the entrance and are baited using about 0.3 kg of Pacific mackerel. Bait and the catch are accessed by the fishermen through the bottom of the trap which is held shut by a drawstring. The main difference in the fishing gear is the lack of weight used in the individual traps, and the fishing ground line and surface line attachment anchor weighs only 16 kg. The traps used by JQC are also of much lighter construction and weigh only 2.5 kg per trap. The number of traps fished per string is 25-28, with an average of 25.6. Fishing has centered around banks off Rota and Aguijan, with little activity near Saipan. No biological data has been recorded on the catches from this second fishing company. Catch, effort, location, and depth information is obtained through log forms completed by the JQC I captain.

# RESULTS

## Catch and Effort

The combined total catch of *H. laevigatus* with incidental capture of *H. ensifer* since May 1994 through February 1996 for both fishing operations is 12,160 kg. Over the period that Laulau Bay Fisheries, Inc. was active in the *Heterocarpus* shrimp fishery a calculated effort of 7,127 trap-nights over 193 days of fishing effort were expended, hauling a calculated catch totaling 8,125 kg of predominantly *H. laevigatus*. The overall catch rate for all locations fished was calculated to be 1.14 kg/trap-night based on information recorded from the vessels' log books and from CPUE data recorded on site by DFW personnel (Table 1).

Total catch for the JQC I from December 1995 through March 2, 1996 is estimated to be 4,035 kg which represents an approximate effort of 20 days fishing and 4,580 trap nights with an overall catch rate of 0.87 kg/trap-night (Table 2). The target species is *H. laevigatus*, and catches are essentially pure (Fig. 7) (Dan Gautier, personal comm.). The mean catch rate is based on log information from 61 sets of traps. The total harvest for the JQC I is based on the estimates of catches from two prior fishing trips plus the sums of the catches of individual sets of traps recorded for the two following trips on DFW logbook forms.

## Bycatch

In addition to Heterocarpus shrimp, other species retained by the traps included deepwater eels of the genus *Synaphobranchus*, squaliforme dogfish sharks, and a large number of two species of Geryonid crabs.

## Location

Trapping effort of LBF was concentrated on the Marpi reef area north of Saipan and to a lesser extent areas northwest and southeast of Tinian (Table 3 and Fig. 1). For the JQC I most of the fishing activity has occurred west of Rota (Table 4 and Fig. 1).

## Depth

The mean depth fished by LBF was 605 m, with a range of 401-747 m. Over 73% of trapping occurred within the depth range of 550-650 m. Trapping effort by the JQC I was concentrated in deeper waters with a mean depth of 670 m, with a range of 580-838 m. Seventy-four percent of trapping took place in the depth range of 600-700 m. The overall mean depth fished for data taken from both fishing operations is 614 m. The depth fished ranged from 401 to 838 m.

## Depth of Greatest Abundance

JQC data from Rota were used to plot the depth of greatest abundance of *H. laevigatus*. Catch rates peak in the 640 to 660 m depth interval (Fig. 10).

## Gear Loss

LBF logbook records on individual sets of traps showed that complete or partial sets of traps were lost at a rate of 3.5% per trap set. This figure represents the probability that some or all of the traps from a set of traps will not be recovered after that set is deployed.

## Biological Samples from LBF Catches

Samples were taken on a weekly basis totaling 17 sample days. A total of 68.4 kg of shrimp were examined, species identified, sex determined, and carapace lengths measured. Of the combined samples, 97.5 % by number and over approximately 99% by weight were *H. laevigatus* (Table 5). Only 8 of 41 trap sets caught *H. ensifer*.

### Mesh Size and Catch Composition

Using the regression equation for carapace length (CL) and carapace width (CW) determined for *H. laevigatus* in Dailey and Ralston (1986) and setting the carapace width equal to the minimum mesh dimension of the trap, the carapace length of 38.4 mm was determined to be the length at which all shrimp are retained in the traps, excluding escape through the trap entrance. *H. ensifer* being the smaller species and having an asymptotic size less than this value should have very little susceptibility to these traps and catches should be mostly *H. laevigatus*. Indeed in very few *H. ensifer* were encountered in the samples. Length at sexual maturity ($L_M$) for female and male *H. laevigatus* has been determined to be 42.7 and 35.7 mm, respectively (Moffit and Polovina 1987). Of *H. laevigatus* caught by LBF, 78.4% of females and 97.8% of males had reached size at maturity. The total catch was comprised of 50.5 % reproductive size female *H. laevigatus*.

### Length Frequency Distribution

The mean carapace length of *H. laevigatus* examined in this study is 45.7 mm, s = 5.5, with a range of 24.1-59.4 mm (Fig. 11). The mean carapace length for males was 42.8 mm while the mean for females was 46.7 mm (Figs. 12 and 13). Gravid female *H. laevigatus* had a mean carapace length of 48.5 mm (Fig. 14). For *H. ensifer* the mean was 30.4 mm, s = 2.4, with values ranging from 24.4-36 mm (Fig. 15).

### Variation in Size with Depth

Mean carapace length for *H. laevigatus* appears to be fairly uniform across the depth range fished for both female and males (Figs. 16, 17, and 18).

### Seasonality in Reproduction

LBF fishermen reported high incidence of berried females beginning in the fall and continuing through the winter. Limited data indicates that the reproductive season for *H. laevigatus* occurs during the winter months and tapers off in the end of March (Fig. 19). In the initial stages of the sampling in February, sex was discerned only where eggs were present, and shrimp with carapace lengths greater than the maximum size for males were assumed to be female. Of shrimp in this size class, 61.5% were berried.

### Sex Ratio

Of the 1,533 *H. laevigatus* that were examined for sex, 406 specimens were male and 1,127 were female producing an overall male to female sex ratio of 0.36. For individual sample days sex ratio was consistently biased toward females (Table 6). Sex ratio was more highly skewed towards females for *H. ensifer* with only 1 male and 46 females harvested for a ratio of 0.02.

Sex ratio for *H. laevigatus* appears to be related to depth and size. The percent of male shrimp taken increases with depth (Fig. 20). The percentage of males caught generally decreases as carapace length increases with the largest size classes being nearly all females (Fig. 21).

## DISCUSSION

### Catch and Effort

For the LBF fishing operation the calculated total harvest of 8,026 kg of primarily *H. laevigatus* agrees extremely well with the 5,100 kg total landings from data obtained from the buyer for the period of November 1994 to May 1995. These total landings recorded from resale data account for 63.5% of the total calculated landings, while the amount of effort expressed as days fished corresponding to that period is 63.7% of the total number of days fished. The total catch figure of LBF is dependent on the calculations of the number of traps fished per string, the number of strings set per day, and the average catch per trap-night. The number of traps per string averaged 12.7 traps, which is taken from known effort recorded on sampling dates and from entries in the vessel log (n = 25). The average number of strings of traps per day was 2.9, while the overall catch per trap-night is the average of the catch rates for 29 sets where effort and catch were recorded. The total harvest figure of 8,026 kg is also very close to the estimated catch of 17,000 lb (7,727 kg) which one of the fishermen reports for the total period.

There are no catch records for the initial trips of the JQC Fishing Company; however, the estimates given by one of the fishermen agree with information the log forms. The estimate of 1,227 kg supplied to DFW for the catch of the third Rota trip is very close to the 1,173 kg total weight figure from the log forms; therefore, the estimates for the earlier fishing trips by the same source may be viewed as reliable. There was some limited trial fishing that is not included in the total catch figure and the catch from these initial cruises is unknown. The estimated total catch of 4,035 kg is therefore likely to be a slight underestimate of the actual total catch for the JQC I through February 1996.

The catch rates reported here for Rota and the composite rate for all areas fished by LBF are within the fairly tight range of 1.02-2.45 kg/trap-night of those reported for previous experimental fishing (Table 5). A high catch rate of 2.39 kg/trap-night was obtained off Rota and is also within the range of the values previously obtained in the Mariana Archipelago. A notable exception is the low catch rate of 0.24 kg/trap-night encountered by the JQC I for fishing grounds near Aguijan. This may be due to previous fishing activity by the LBF operation on the same limited fishing grounds. Although there are no recorded catch rates for the area around Aguijan from the LBF data, there was some fishing activity in the area. It is also likely that the JQC I fished the grounds prior to the February 1996 trip. Ralston (1986) demonstrated the dramatic decline in CPUE that can be seen when a small area is fished heavily. A decline from 3.3 to 1.8kg/trap-night over 16 days was recorded in an intensive fishing experiment off Alamagan. A similar drop from the 1.62 kg/trap-night rate recorded for Aguijan by Moffit and Polovina (1987) to the 0.24 kg/trap-night figure is plausible given the high susceptibility that *H. laevigatus* is reported to have to trap fishing (Ralston, 1986).

Catch rates reported from this study represent rates for a fishery that has already experienced some fishing pressure. Catch-per-unit-effort data from the early period in the fishery is lacking and catch rates were likely to have been somewhat higher when fishing activity began in a given area. Rates reported in the other studies are for areas that have received little or no prior fishing pressure.

Catch rates may also be influenced by trap design. This effect is unknown and in need of further investigation. Comparisons of catch rates between studies using different traps must therefore be treated with caution. However, all of the traps utilized in the studies below are similar in volume and catch rates are within a fairly tight range. This supports the validity of comparing performance of different trap designs.

Comparisons between commercial and scientific trapping must also be viewed with caution because of a commercial venture's tendency to exploit a fishery more efficiently. Previous work in the Mariana Archipelago has been restricted to scientific trapping which may possibly give lower estimates of the catch rates because there was not an economic incentive to maximize catch rate and also because of the wider depth range usually fished. In contrast, a commercial fishing venture will try to place traps within the depth range of greatest abundance and as a result catch rates should be higher. Assuming that comparisons of the different studies are useful and that both fishing companies exploited the fishery efficiently and maximized their

catch rates, it can be concluded that catch rates for the commercial shrimping in areas around Saipan and Rota are similar to rates published in prior resource assessment surveys, but rates are likely to have dropped since the time of initial exploitation. The catch per trap-night off Aguijan is almost seven times less than the what has been reported previously (Moffitt and Polovina 1987). This decline is probably a result of fishing mortality.

## Depth of Greatest Abundance

The paucity of data recording complete catch rate, depth, and location information for LBF catches prohibits any analysis of depth of greatest abundance for *Heterocarpus* shrimp caught by the company. It is a reasonable assumption, however, that since the LBF was a commercial venture, they would be trying to maximize catch rates. The depth range of 550-650 m in which the majority of fishing occurred likely represents the depth of greatest abundance for the target species, *H. laevigatus,* over all fishing grounds, but concentrated around Saipan and Tinian. The mean depth fished at the Marpi reef area of Saipan, where 69% of effort was expended, was 601 m. The depth range of greatest abundance of *H. laevigatus* for grounds around Rota can likewise be assumed to correspond to the mean fishing depth of 661 m. Figure 10 shows a maximum catch rate of 2.39 kg/trap-night at a depth of 657 m in Rota waters. Catch rates are maximized at around 650 m, which roughly corresponds to the mean depth fished at that location. The depth range of 550-700 m in which most of the fishing took place for both companies combined concurs with the depth range of maximum abundance for *H. laevigatus* of 549-777 m reported for the Marianas (Moffitt and Polovina 1987), and includes the optimum depth of 680 m reported for Guam (Wilder 1977). The depth fished is also consistent with the 500 to 800 m range which was found to have the highest catch rate of *H. laevigatus* for the Northwestern Hawaiian Islands (Gooding 1984).

*H. laevigatus* occurred at a mean depth of 616 m in the biological samples. The mean depth at which the *H. ensifer* were encountered in the samples was 557 m, somewhat less than the overall mean fishing depth. The greatest depth in which *H. ensifer* was recorded is 660 m.

## Seasonality in Reproduction

A distinct reproductive period for *H. laevigatus* occurs in the fall and winter months in the Mariana Archipelago, with a large percentage of females bearing eggs from November through February, declining in March. This is consistent with the findings of previous work for the fall and winter spawning period (Moffitt and Polovina 1987; Wilder 1977). However, in the spring time virtually no females were berried, in contrast to the result of Wilder (1977), who reported an additional spring spawning period for shrimp near Guam.

## Sex Ratio

Biased sex ratios have sometimes been taken as evidence of sex reversal in marine crustaceans (Wenner 1972). Deepwater shrimp were originally thought to be protandrous hermaphrodites (Clark 1972; Wilder 1977; King 1981c), but have since been shown to be dioecious and to not undergo sex reversal (King and Moffitt 1984). Sex ratio for *Heterocarpus* shrimp has been shown to be related to depth, size, and season (Moffitt and Polovina 1987; Dailey and Ralston 1986). In this study the sex ratio of *H. laevigatus* is biased towards females and approaches a 1:3 male to female ratio. This is in contrast to the results of Wilder (1977) for *H. laevigatus* caught near Guam where sex ratio is over 3:1 male to female for depths 549-732 m and also departs from the overall 1:1 ratio previously observed for the Marianas (Moffitt and Polovina 1987).

Moffitt and Polovina (1987) observed that the largest size classes of shrimp are nearly all female. This may help explain why nearly all of the *H. ensifer* examined in this study were females. The mean size of 30.4 mm for *H. ensifer* trapped is in the upper end of the size range for the species and close to the asymptotic size ($L_\infty$) value of 36.6 mm reported by Moffitt and Polovina (1987). The same line of reasoning may also partially explain the high proportion of female *H. laevigatus* that were encountered in this study. It is known that males do not grow as large as females, $L_\infty$ = 51.3 mm for males and $L_\infty$ = 55.4 mm for females (Moffitt and Polovina 1987). If the true sex ratio is equal, a difference in size among the sexes does exist, and shrimp are caught using a mesh size that retains only the larger size classes of shrimp, then it may be expected that a great percentage of shrimp caught would be large females. The sex ratio is biased towards females as size increases from a relatively equal proportion of males and females to nearly all females in the largest size classes (Fig. 21). It is possible that the true sex ratio may actually be equal, but that the traps used in this study had a mesh size that selected larger shrimp which were disproportionately female in the larger size classes.

In previous research sex ratios have been shown to vary with depth. Dailey and Ralston (1986) found relatively fewer females as depth increased for *H. laevigatus* in Hawaii. For the Mariana Islands and Guam, *H. laevigatus*, *H. ensifer* females were more abundant in the shallower depths fished and males more abundant at deeper depths (Moffitt and Polovina 1987; Wilder 1977). For this study a similar trend was observed for *H. laevigatus* with the percentage of males rising from 16% in the 450-550 m depth range to 35.4% for 650-750 m depths (Fig. 20). However, this figure is still less than the 50-60% male composition for the 650-750 m depth range reported in Moffitt and Polovina (1987). Any comparisons must be made with caution because the samples taken here are from the post-reproductive period. Data in Moffitt and Polovina (1987) represent samples taken during both spawning and non-spawning seasons. Dailey and Ralston (1986) present evidence that *H. laevigatus* in Hawaii undergoes a seasonal migration in depth following the reproductive cycle of the females. Distributions of large shrimp of both sexes shifted to depths approximately 150 m deeper during the reproductive period. Differences in sex ratio compared with figures from previous studies may reflect seasonal migrations or differences in catchability based on sex as has been suggested for *H. laevigatus* in

Hawaii by Dailey and Ralston (1986). Another explanation of the skewed sex ratio presented here is a possible greater natural mortality of male shrimp (Dailey and Ralston 1986).

## Viability of the Fishery

### Economic considerations and gear loss

The economic viability of the local *Heterocarpus* shrimp fishery seems in question given the closure of LBF fishing operation. The reasons LBF cited for closing down fishing operations were slightly declining catch rates and a large amount of gear loss. The high cost in replacing lost gear was the single most important consideration in not continuing trapping. Over the course of the year's operation nearly 300 traps were lost due to fouling on the bottom, currents, sharks, and vandalism. The rate of partial or total gear loss from logbook data was at least 3.5% per trap set. The primary cause of gear loss was most likely fouling on the bottom, which may have been reduced if the traps were less heavily weighted. This rate of gear loss does seem reasonable given the great depths that are fished and the experiences of trapping from other islands. Fishing with large pyramidal traps of re-bar and wire mesh, a commercial shrimping company operating in Hawaii experienced similar gear loss at a rate of 3.35 % (Tagami and Barrows 1988). These traps were like the Fathom Plus traps used by LBF in that they are heavy and rigid; however, they were fished using only a single trap per floatline. Saunders and Hastie (1989) report 7% gear loss for strings of rectangular box traps fished in Palauan waters.

Using lightweight traps, fishermen from the JQC Fishing Company report almost no gear loss due to snagging (Dan Gautier, pesonal comm). Lightweight traps may snag on an irregular bottom feature, but then collapse or tear free, allowing the rest of the trap line to be hauled. Although not as durable as metal and hard plastic designs, lightweight traps are significantly more inexpensive and are able to nest, saving deck space. It is uncertain how different trap designs, weight, and gear setups influence gear loss. Because of the high rate of gear loss that can be expected for this fishery, it is recommended that companies weigh the costs and benefits of fishing performance, durability, and trap cost for individual traps carefully before investing in large numbers of traps. Trap performance and relative rates of gear loss are important areas for future fisheries development research.

### Sustainable Yield

The sustainable yield estimate projected by Moffitt and Polovina (1987) of 70 t/year for fishing grounds around Saipan and Tinian or 162 t/year for the whole archipelago has yet to be realized. The total estimated catch by LBF of 8,125 kg (8 t) represents 193 days of effort over about a year concentrated in Saipan and Tinian waters. This figure for total landings is far short of initial estimates for an annual equilibrium yield for the these islands. There are perhaps a number of reasons why the total landings have not met the projected annual yield. The yield estimates may not be realistic. The annual yield is based on the assumption that shrimp are distributed evenly over the bottom and that they are equally catchable in all areas. This may not

be the case, as LBF fishermen have observed that the *H. laevigatus* occur in dense "pockets" and seem to be associated with volcanic substrate types. Moffitt and Parish (1992) also noted an apparent association between *H. laevigatus* and volcanic substrates. Even though an area is within the proper depth for the species, catch rates may be low because the substrate is not suitable. The assumption that all areas of suitable depth are equally fishable also needs to be examined more closely. LBF lost a considerable amount of gear setting traps on areas with steeply sloped or irregular bottom profiles. Areas that would likely have produced high catches of *H. laevigatus* were left unfished because of the high risk of loosing traps and gear. The fishing effort was limited and not extensive and widespread enough to obtain a total catch that approaches the annual yield. This is supported by the fact that catch rates were in the range of those obtained in previous studies. Had the fishing effort by LBF been more intensive, catch rates would likely have dropped below levels that are reported here. Increases in annual yield above the 8,125 kg/year figure reported here may be possible for a local Saipan and Tinian fishery; however, this would require a greater level of fishing effort and catch rates would be expected to fall. When a fishery is being exploited at the point of maximum sustainable yield catch rates should be roughly half of what was recorded in the initial surveys (Munro and Fakahau, 1986). For the Northern Mariana Islands, CPUE figures in the range of 0.5-1.0 kg/trap-night may be expected for long-term exploitation. For most areas around Saipan and Tinian, catch rates remain close to those from the initial resource surveys, indicating that the fishery is in a state of relatively light exploitation. Depressed catch rates for areas off Aguijan, west Saipan, and northwest Tinian suggest that those areas may be overfished.

**Recommendations for the Fishery**

Garcia et al. (1987) suggest a target for initial exploitation of a virgin stock of between 1/3 and 2/3 maximum sustainable yield as an upper harvest limit for fisheries managers to aim for in developing a fishery. This level of exploitation does not seem to be forthcoming, and overcapitalization of the fishery here may not be as much of a problem as the high costs of fishing in deep water. Traps should be as inexpensive as possible to offset probable high rates of gear loss that seem inherent in this fishery. Another measure that would lower costs would be the use of a smaller fishing vessel, which would be feasible since great range is not necessary to reach fishing grounds. Moffitt and Polovina (1987) projected that 85% of the total yield for the archipelago would come from the southern islands.

With the exception of the regulation of trap design to limit ghost fishing, regulating the fishery may not be immediately necessary. The risk of losing gear combined with other costs will make it uneconomical to set traps for shrimp once catch rates have declined significantly. Furthermore, all areas are not equally fishable and those areas that are high risk areas for placing traps will be left unfished and may provide a refuge for a spawning stock to replenish other areas. Similar to the *Heterocarpus* fishery in Hawaii, this fishery would seem to be self-regulating in that it becomes uneconomical to fish before the annual equilibrium yield is reached, thus stocks are given time to recover.

Although *H. laevigatus* is the largest and the more marketable of the shrimp species, it may be worthwhile for an interested company to try and develop markets for *H. ensifer* and the geryonid crabs that were frequently trapped. Moffitt and Parrish (1992) suggest that a small vessel might maximize overall catch and profits by fishing for *H. ensifer* through making a couple of short soaks in the daytime, and then moving to *H. laevigatus* fishing grounds for an overnight soak. *H. ensifer* shows high activity around baited traps and requires only short soak times (Moffitt and Parrish 1992). *H. ensifer* is also found in shallower waters which should reduce gear loss. Geryonid crabs were encountered frequently in LBF shrimp traps and may have promise as a live specialty item for local restaurants and international markets. Saunders and Hastie (1989) found a favorable reception in Tsukijii Japanese market trials of crabs caught in shrimp traps from Palau. With the combination of numerous expensive local seafood restaurants, close proximity and daily flights to Japan, obtaining a reasonable ex-vessel price for these products and marketing them should be possible and sustainable for a small fishing company operating out of Saipan.

This and previous work indicate that there is potential for expansion in the Northern Mariana Island deepwater shrimp fishery. Sustaining fishing effort over the long term may be economically viable only with a reduction in fishing costs and broadening the range of target species. Economic constraints are certain play a major role in the development of this fishery.

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# TABLES

Table 1.--Catch, effort, and catch rates by area for catches of predominantly *Heterocarpus laevigatus* caught by the Marlin II on fishing trips during the period from November 1994 through June 1995.

| | SE. Tinian | NW. Tinian | 300 Reef Saipan | W. Saipan | Marphi Reef Saipan | N. Seamounts SPN-ATN | Anatahan | Totals |
|---|---|---|---|---|---|---|---|---|
| Period fished | 3/95 | 3/95 | 6/95 | 11/94-3/95 | 11/94 | 1/95-2/95 | 4/95 | |
| No. of traps fished | 48 | 40 | 10 | 23 | 100 | 166 | 5 | 392 |
| No. of sets of traps | 6 | 5 | 2 | 2 | 4 | 7 | 1 | 27 |
| Catch of *Heterocarpus* (kg) | 66.8 | 28.8 | 15 | 13.2 | 171.8 | 145.4 | 7.7 | 448.7 |
| Mean catch rate (kg/trap-night) | 1.39 | 0.72 | 1.50 | 0.57 | 1.72 | 0.88 | 1.54 | 1.14 |

Table 2.--Catch, effort, and catch rates by area for catches of predominantly *Heterocarpus laevigatus* caught by the JQC I on three cruises from December 1995 through February 1996.

| | Rota | 300 reef Saipan | Aguijan | Totals |
|---|---|---|---|---|
| Period fished | 12/95 | 1/96 | 2/96 | |
| No. of traps fished | 850 | 234 | 477 | 1561 |
| No. of sets of traps | 34 | 9 | 18 | 61 |
| Catch of *Heterocarpus* (kg) | 1173.4 | 66.2 | 112.5 | 1352.1 |
| Mean catch rate (kg/trap-night) | 1.38 | 0.28 | 0.24 | 0.87 |

Table 3.--Effort allocation by area. Areas fished by LBF and number of trap lines set per area as recorded in vessel log books for the period of May 1994 to June 1995.

| Area fished | Aguijan | NW. Tinian | SE. Tinian | 300 Reef Saipan | Laulau Bay Saipan | Marphi Reef Saipan | N. Seamounts SPN-ATN | Anatahan | Zealandia Bank | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of sets of traps | 3 | 39 | 31 | 7 | 12 | 284 | 13 | 10 | 11 | 410 |
| % of total from vessel log books | 0.7% | 9.5% | 7.6% | 1.7% | 2.9% | 69.3% | 3.2% | 2.4% | 2.7% | 100.0% |

Table 4.--Effort allocation by area. Areas fished by JQC I and number of trap lines set per area as recorded on DFW log forms for the period of December 1995 through February 1996.

| Area fished | Rota | Aguijan | 300 reef Saipan | Total |
|---|---|---|---|---|
| Number of sets of traps | 34 | 18 | 9 | 61 |
| % of total from DFW log sheets | 55.7% | 29.5% | 14.8% | 100.0% |

Table 5.--Species composition for all samples of shrimp examined from the Marlin II.

| Species | *H. ensifer* | *H. laevigatus* | Unidentified | Total |
|---|---|---|---|---|
| Number | 46 | 1,842 | 1 | 1,889 |
| % by number | 2.44% | 97.51% | 0.05% | 100.00% |
| Estimated weight kg | 0.5 | 67.81 | 0.066 | 68.38 |
| Estimated % by weight | 0.73% | 99.17% | 0.10% | 100.00% |

Table 6.--Sex ratio of *Heterocarpus laevigatus* by sample day.

| Date | 3/3/95 | 3/7/95 | 3/14/95 | 3/27/95 | 3/30/95 | 4/5/95 | 4/13/95 | 4/28/95 | 5/2/95 | 5/9/95 | 5/18/95 | 5/25/95 | 6/7/95 | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Females | 35 | 27 | 258 | 209 | 141 | 32 | 51 | 69 | 83 | 78 | 50 | 72 | 22 | 1,127 |
| % Female | 66.0% | 77.1% | 66.5% | 84.3% | 79.7% | 82.1% | 73.9% | 78.4% | 92.2% | 84.8% | 49.0% | 68.6% | 46.8% | 73.5% |
| Number of Males | 18 | 8 | 130 | 39 | 36 | 7 | 18 | 19 | 7 | 14 | 52 | 33 | 25 | 406 |
| % Male | 34.0% | 22.9% | 33.5% | 15.7% | 20.3% | 17.9% | 26.1% | 21.6% | 7.8% | 15.2% | 51.0% | 31.4% | 53.2% | 26.5% |
| Sex ratio M:F | 0.51 | 0.30 | 0.50 | 0.19 | 0.26 | 0.22 | 0.35 | 0.28 | 0.08 | 0.18 | 1.04 | 0.46 | 1.14 | 0.36 |

Table 7.--Catch rates of *Heterocarpus* shrimp for low volume traps in the Mariana Archipelago.

| Area fished | Catch rate kg/trap-night | Source |
|---|---|---|
| Aguijan | 0.24 | Present study, JQC I data |
| Rota | 1.02 | Moffit and Polovina, 1987 |
| Mariana Archipelago (Aguijan to Zealandia bank) | 1.14 | Present study, Marlin II data |
| Rota | 1.38 | Present study, JQC I data |
| Saipan and Tinian | 1.6 | Moffit, 1983 |
| Aguijan | 1.62 | Moffit and Polovina, 1987 |
| Saipan, Marphi reef | 1.72 | Present study, Marlin II data |
| Tinian | 1.81 | Moffit and Polovina, 1987 |
| Saipan | 2.06 | Moffit and Polovina, 1987 |
| Mariana Archipelago | 2.1 | Moffit and Polovina, 1987 |
| Guam | 2.1 | Wilder, 1977 |
| Alamagan | 2.45 | Ralston, 1986 |

# FIGURES

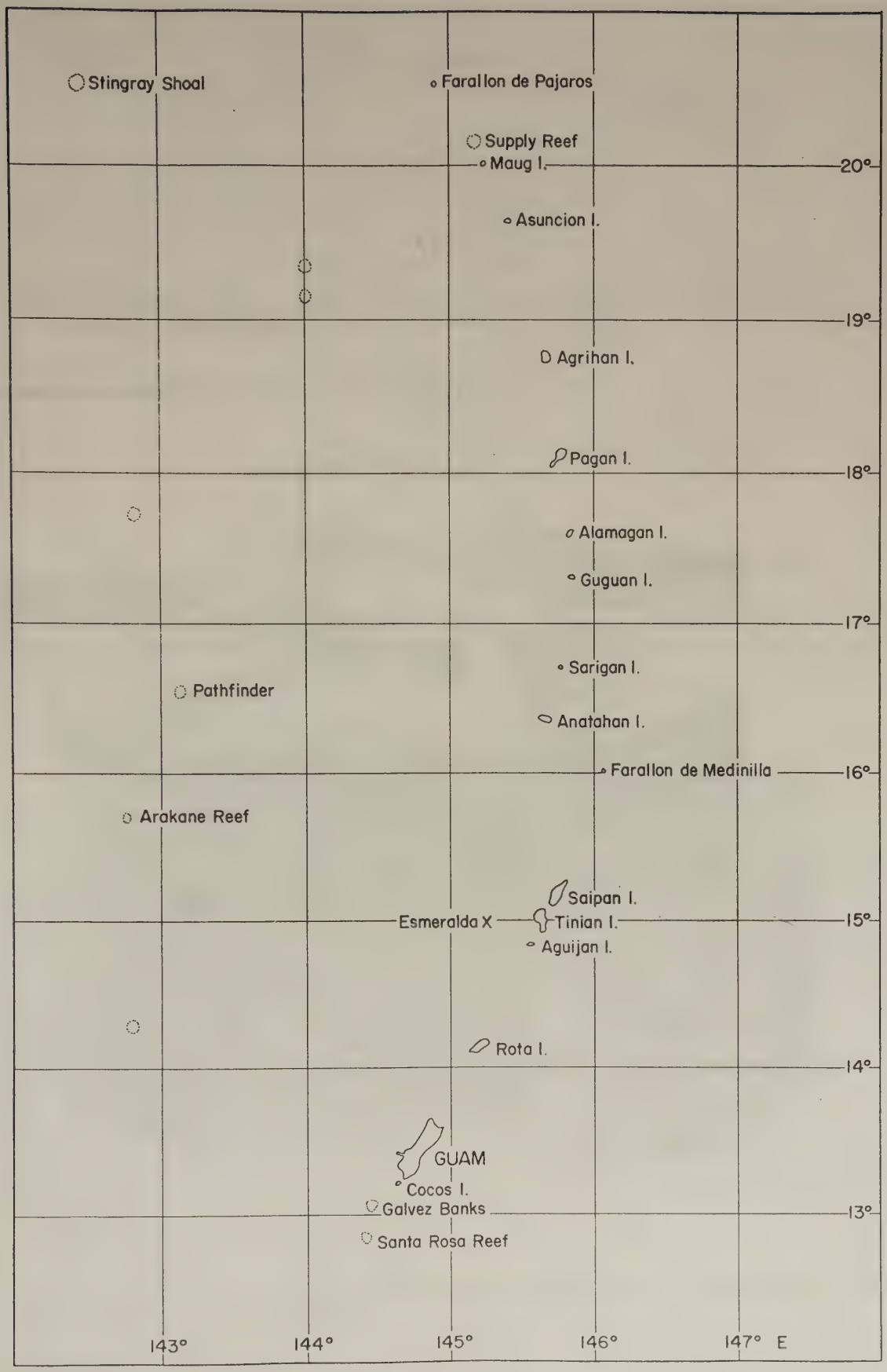


Figure 1.–Map of the Mariana Archipelago.

Figure 2.–Laulau Bay Fishing, Inc. fishing vessel, the Marlin II.

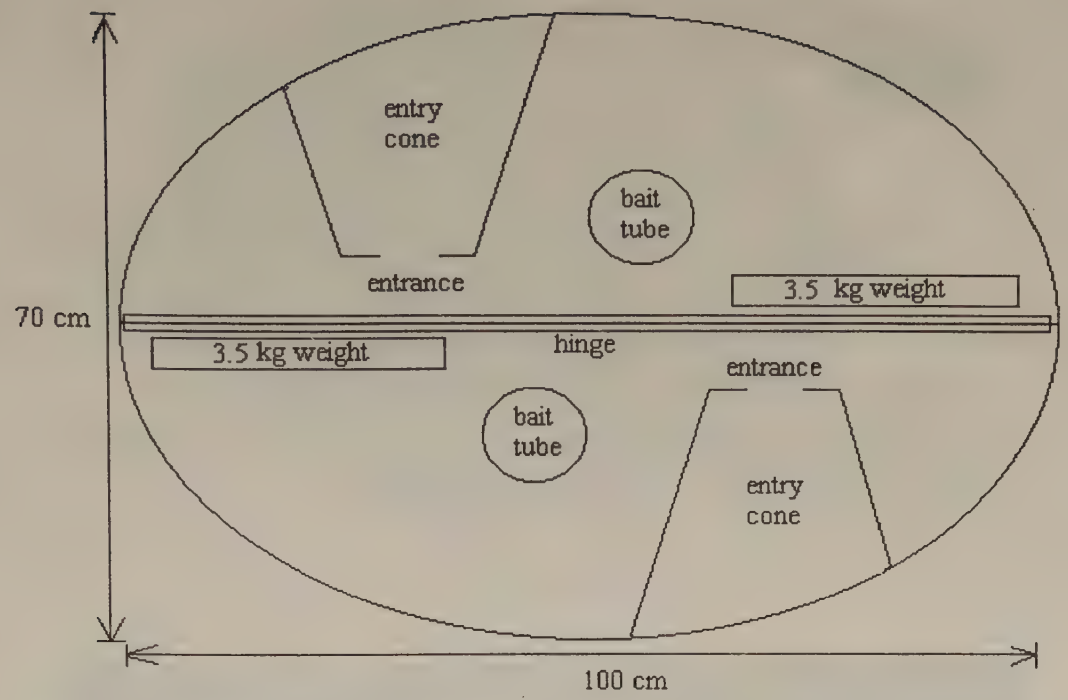


**Figure 3.** - schematic top view of a Fathom Plus trap used by Laulau Bay Fisheries, Inc.

**Figure 4.** - Side view of the Fathom Plus trap from Fathom Plus Inc. San Diego, CA USA part no. FP221.

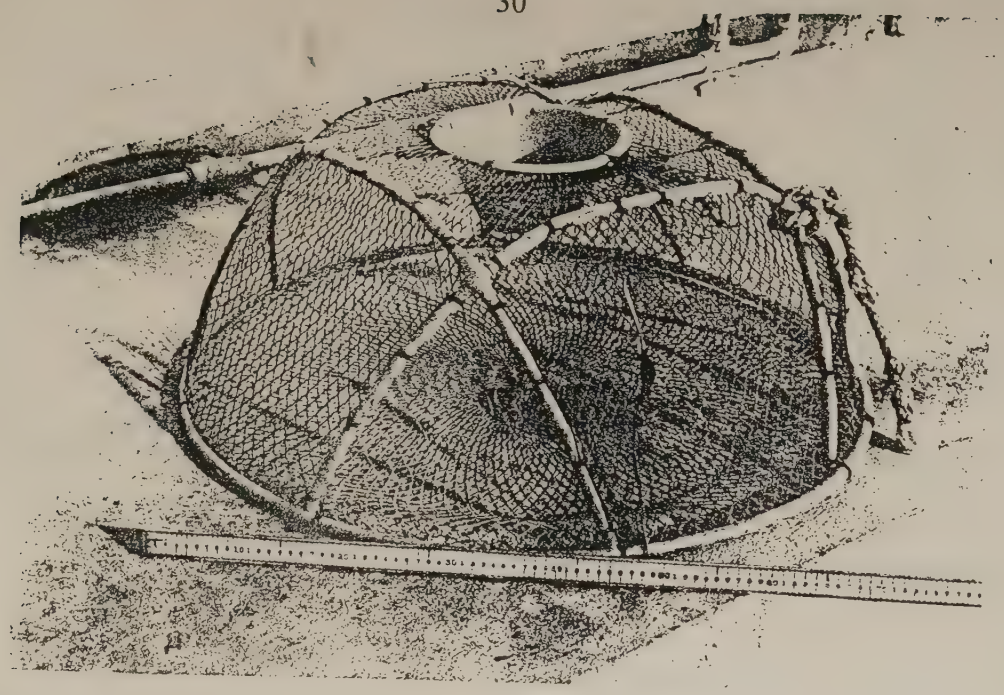

**Figure 5.** - Trap used by the JQC Fishing Company.

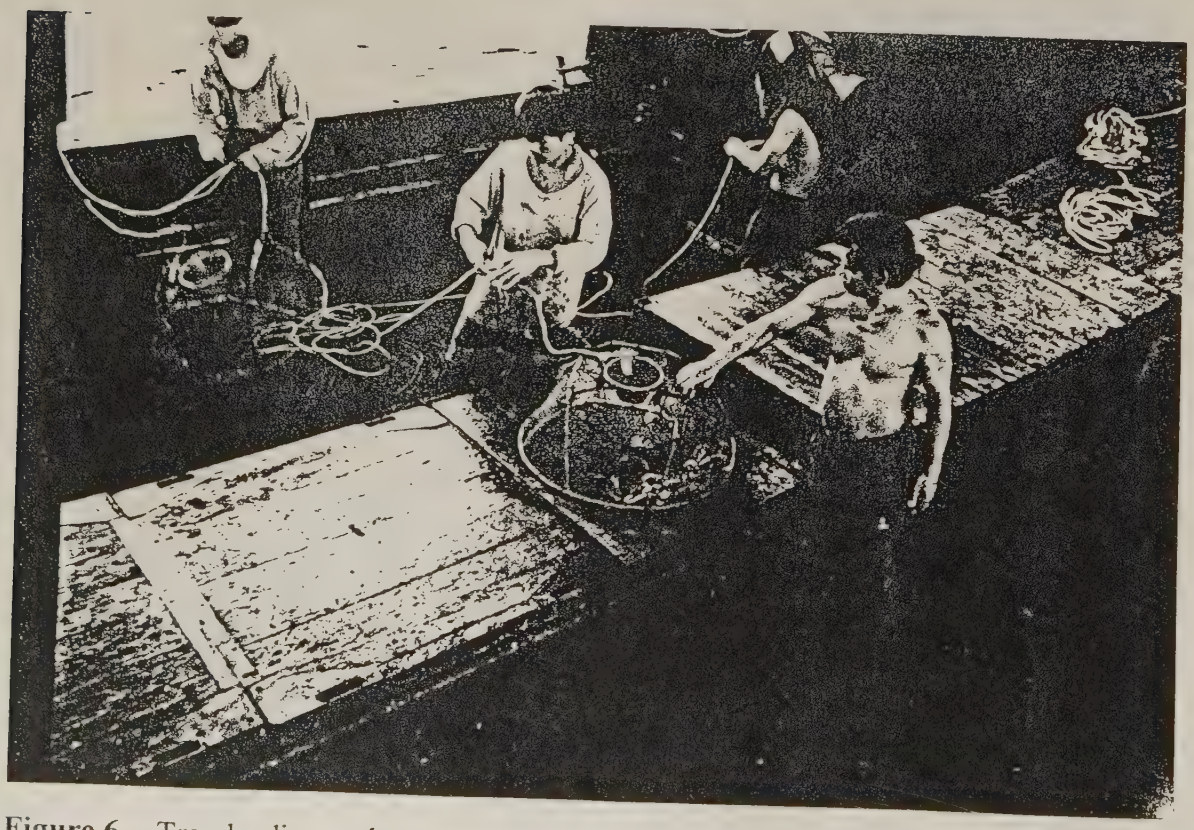

**Figure 6.** - Trap hauling on board the fishing vessel JQC I.

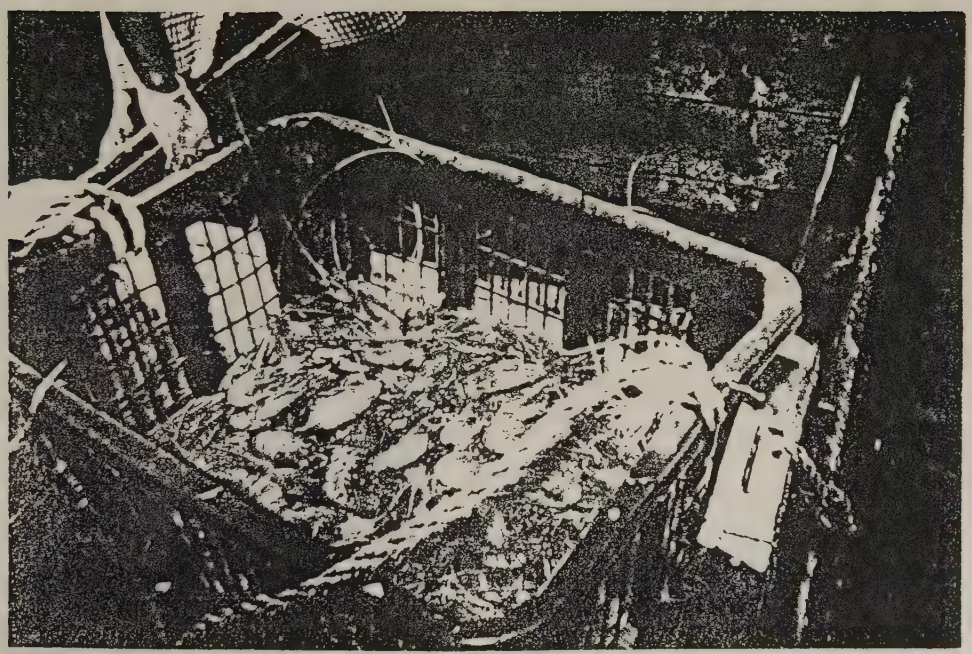

Figure 7.–Catch of *Heterocarpus* shrimp.

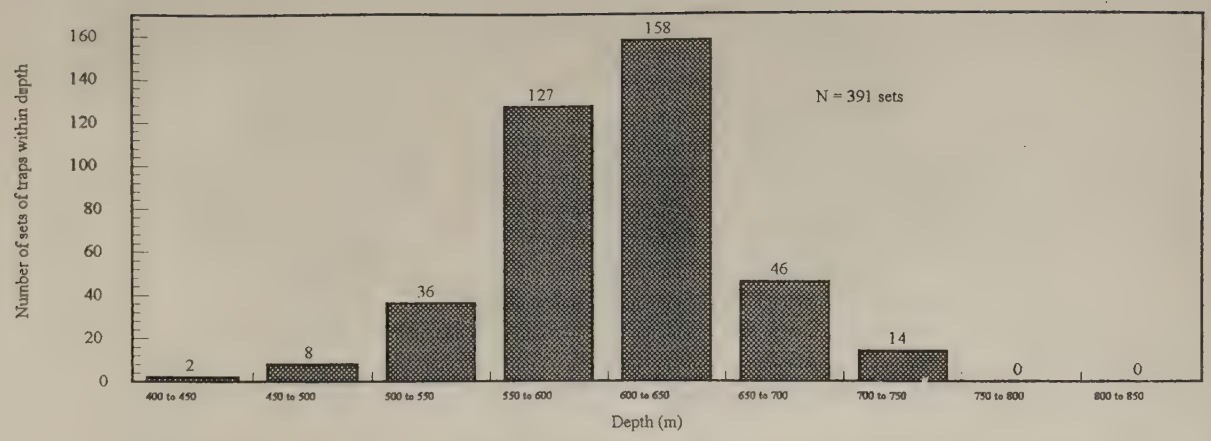


**Figure 8.** - Distribution of average depth fished by the Bluewater Hunter and the Marlin II from May 1994 through June 1995, reported from 391 entries in vessel log books.

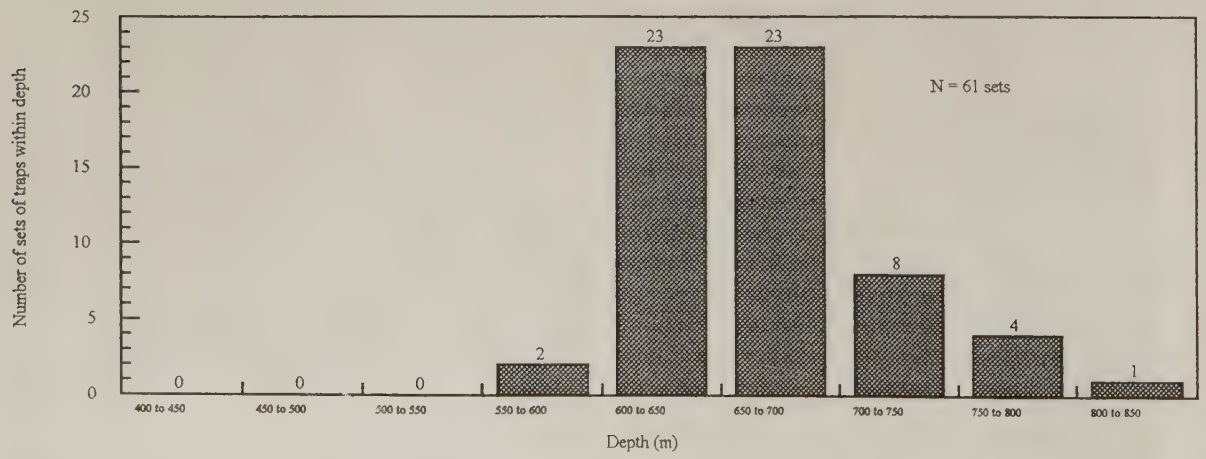


**Figure 9.** - Distribution of average depth fished by the JQC I from December 1995 through February 1996, reported from 61 log book entries.

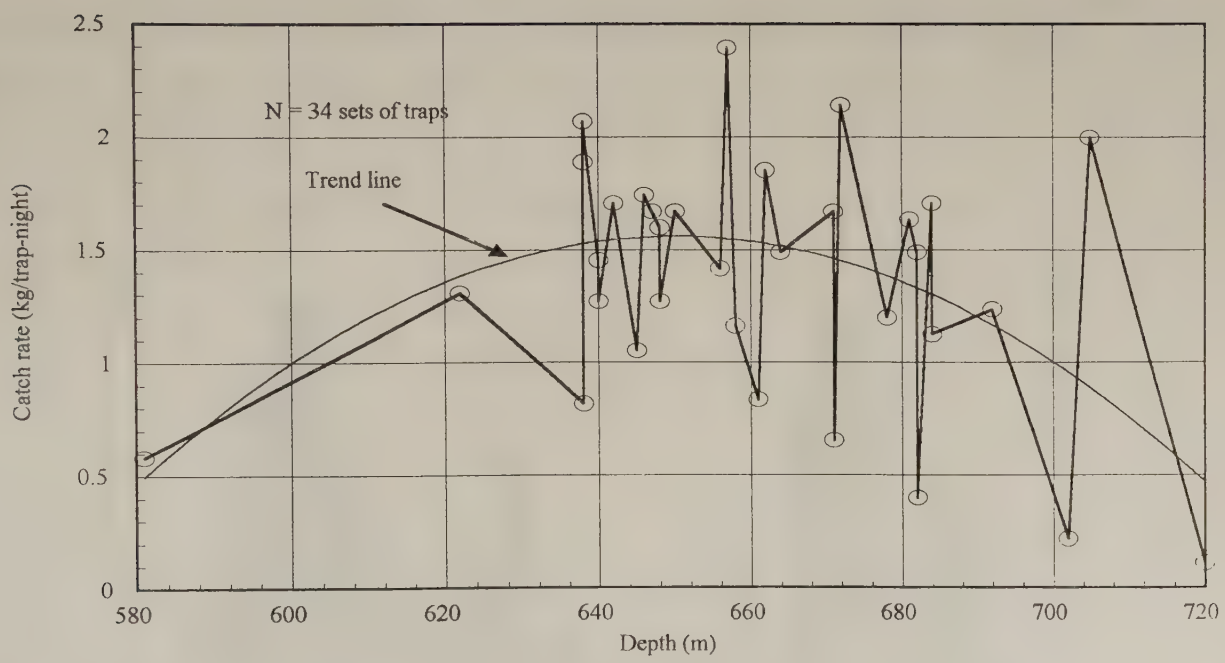


**Figure 10.** - Catch rates of *Heterocarpus* shrimp by depth for shrimp harvested by the JQC I on Rota in December 1995. Each data point represents one set of traps. The trend line represents a four order polynomial model fitted to the data.

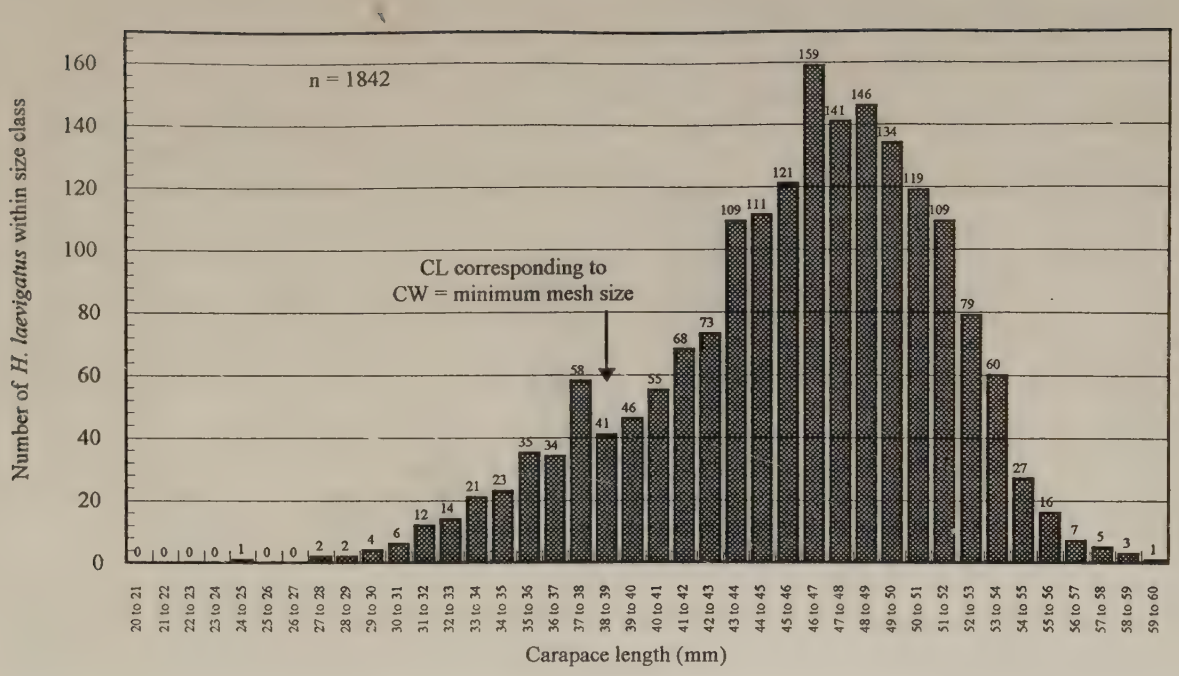


**Figure 11.** - Length frequency distribution of *Heterocarpus laevigatus* taken in traps by the Marlin II.

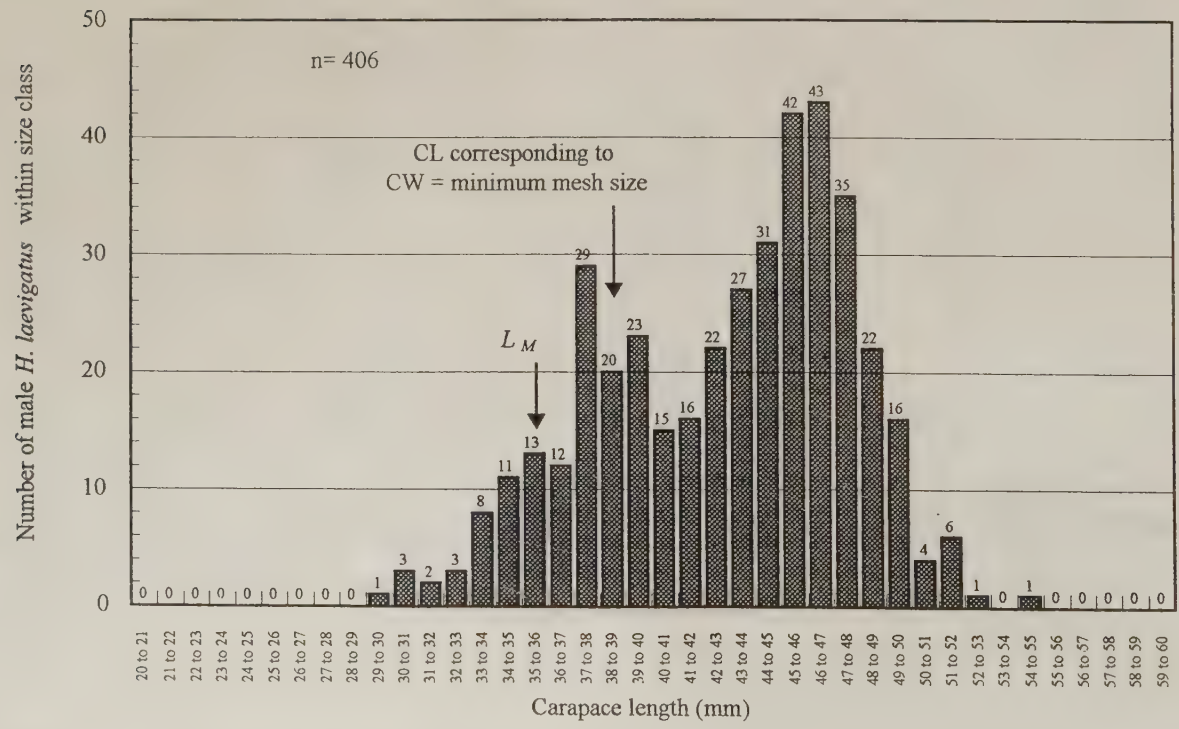


**Figure 12.** - Length frequency distribution of male *Heterocarpus laevigatus* taken in traps by the Marlin II.

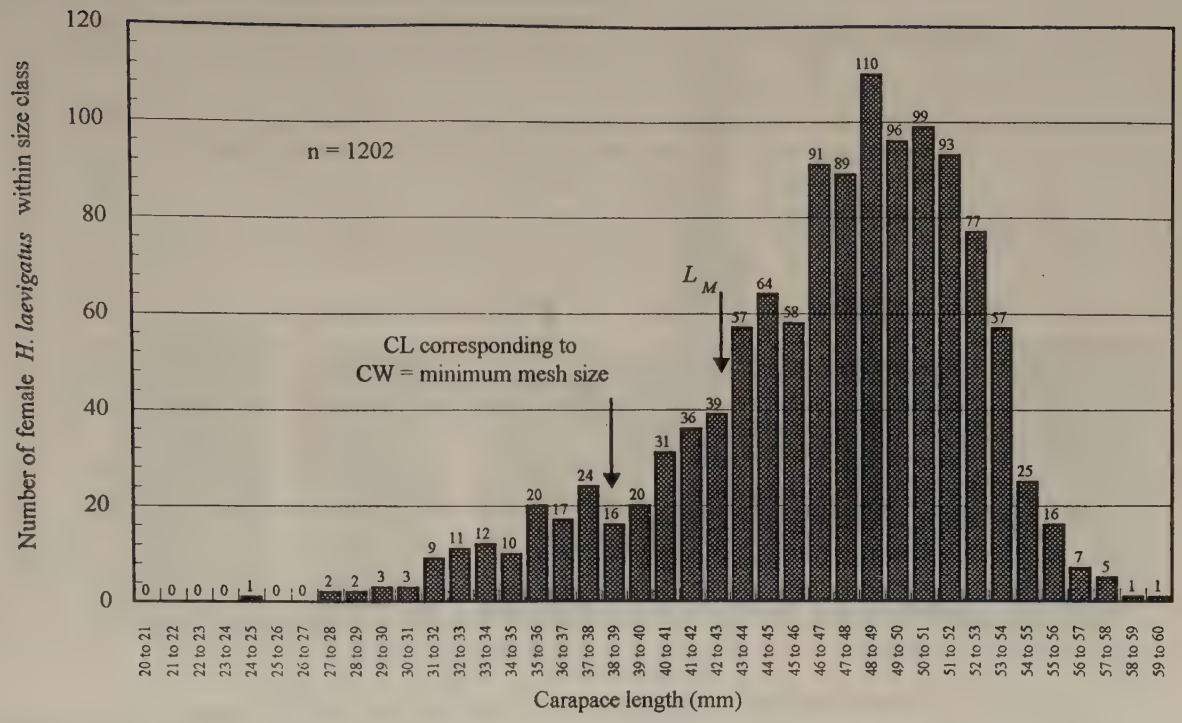


**Figure 13.** - Length frequency distribution of female *Heterocarpus laevigatus* taken in traps by the Marlin II.

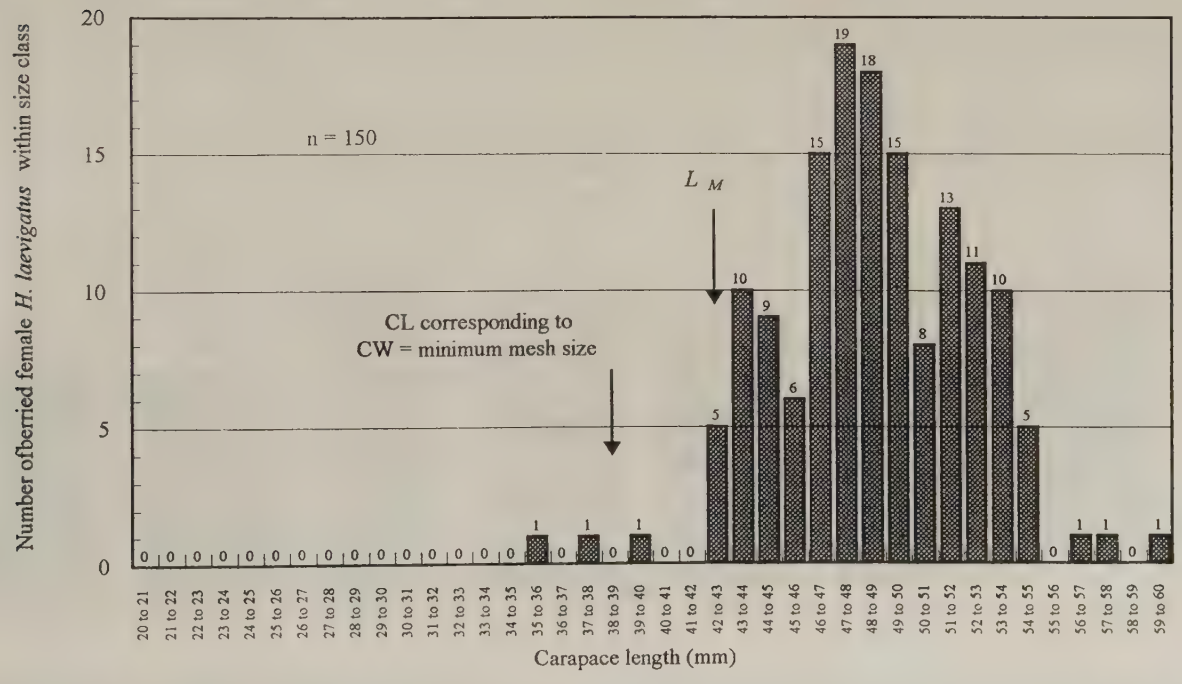
Number ofberried female H. laevigatus within size class
n = 150
L M
CL corresponding to
CW = minimum mesh size
Carapace length (mm)

**Figure 14.** - Length frequency distribution of berried female *Heterocarpus laevigatus* taken in traps by the Marlin II.

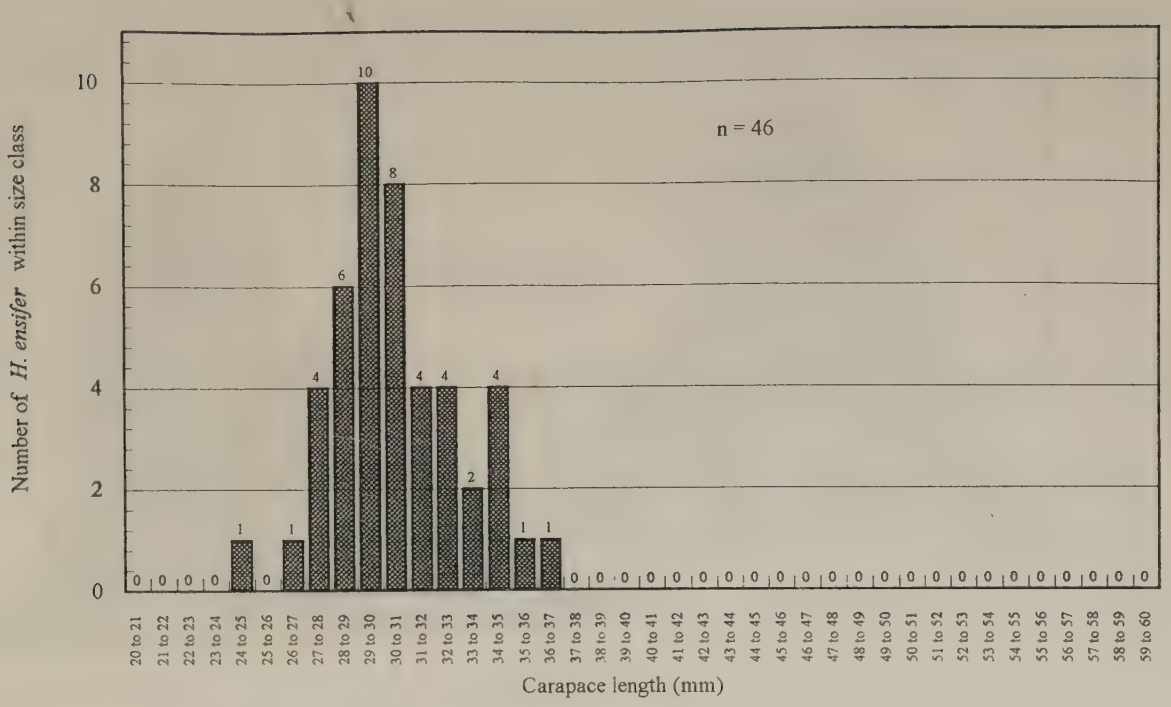


**Figure 15.** - Length frequency distribution of *Heterocarpus ensifer* taken in traps by the Marlin II.

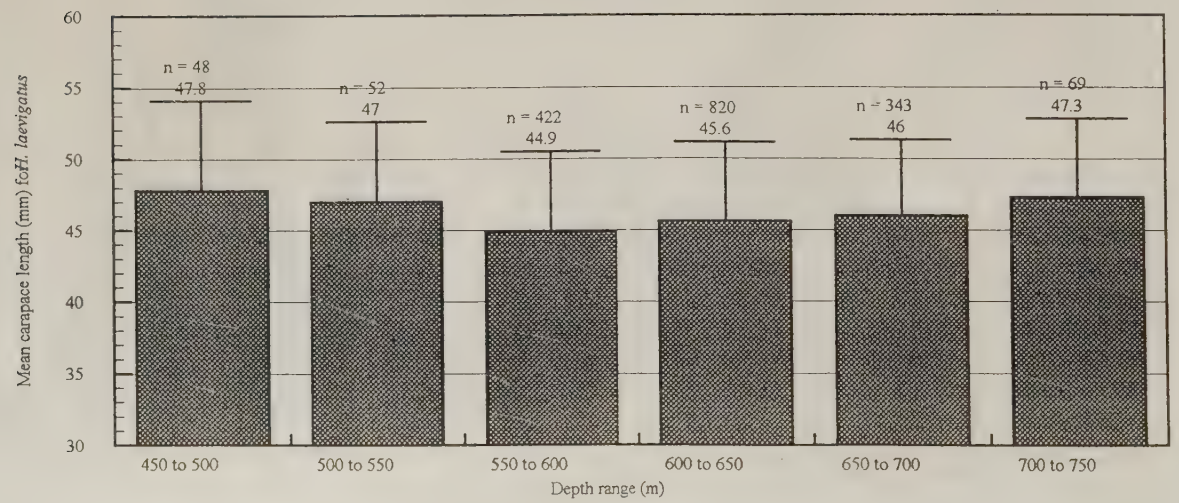


**Figure 16.** - Mean carapace length for *H. laevigatus* by depth over all areas fished by the Marlin II. Error bars represent standard deviations.

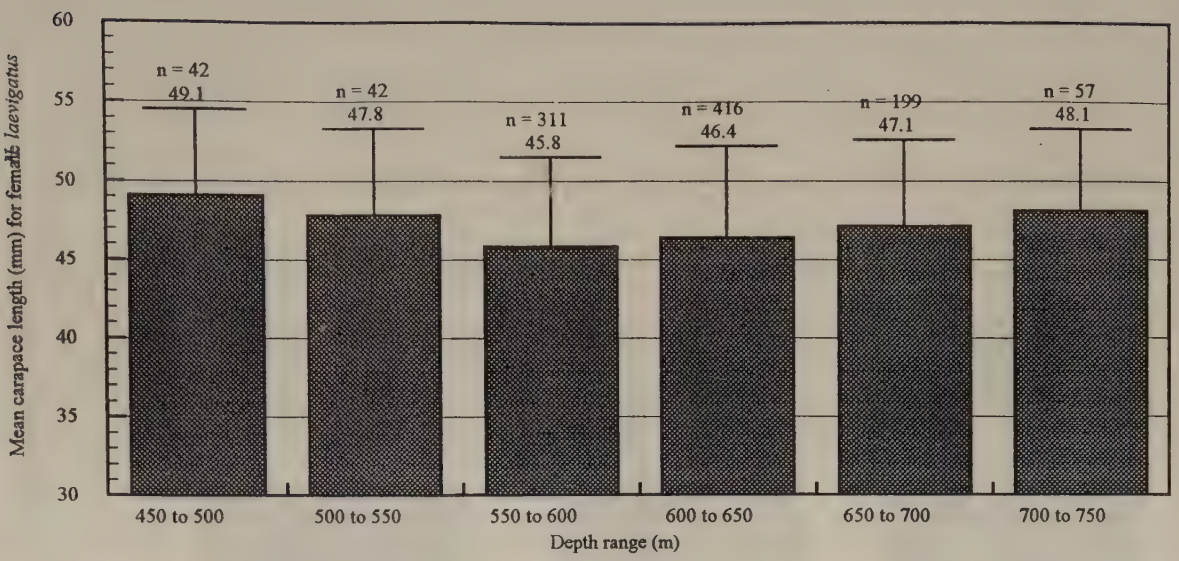


**Figure 17.** - Mean carapace length for female *H. laevigatus* by depth over all areas fished by the Marlin II. Error bars represent standard deviations.

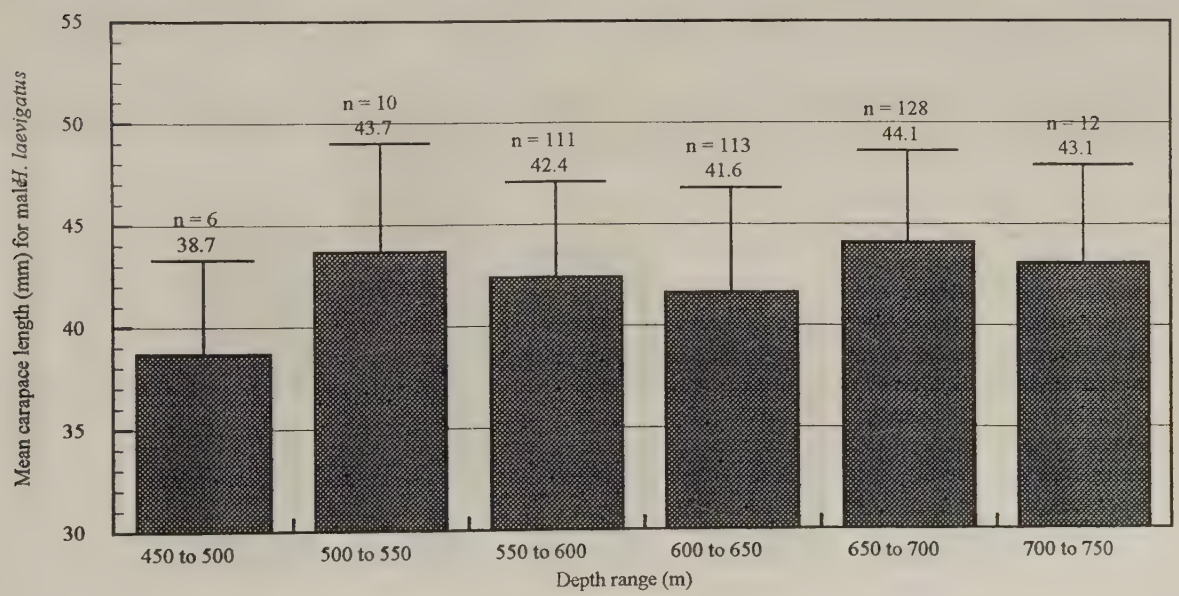


**Figure 18.** - Mean carapace length for male *H. laevigatus* by depth over all areas fished by the Marlin II. Error bars represent standard deviations.

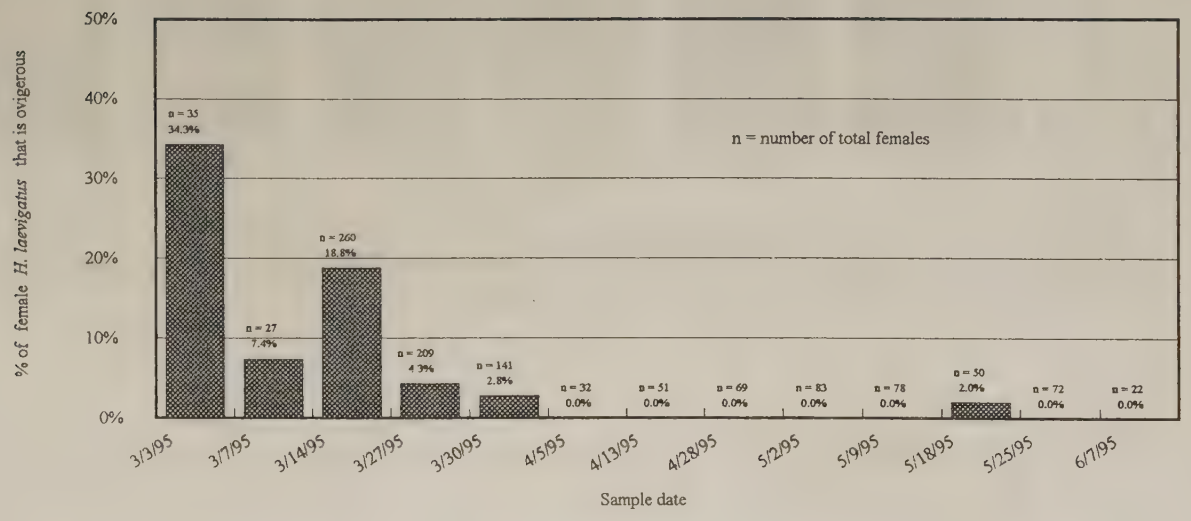


**Figure 19. -** Percentage of female *H. laevigatus* bearing eggs by sample day. Sample sizes indicate the total number of females examined per day.

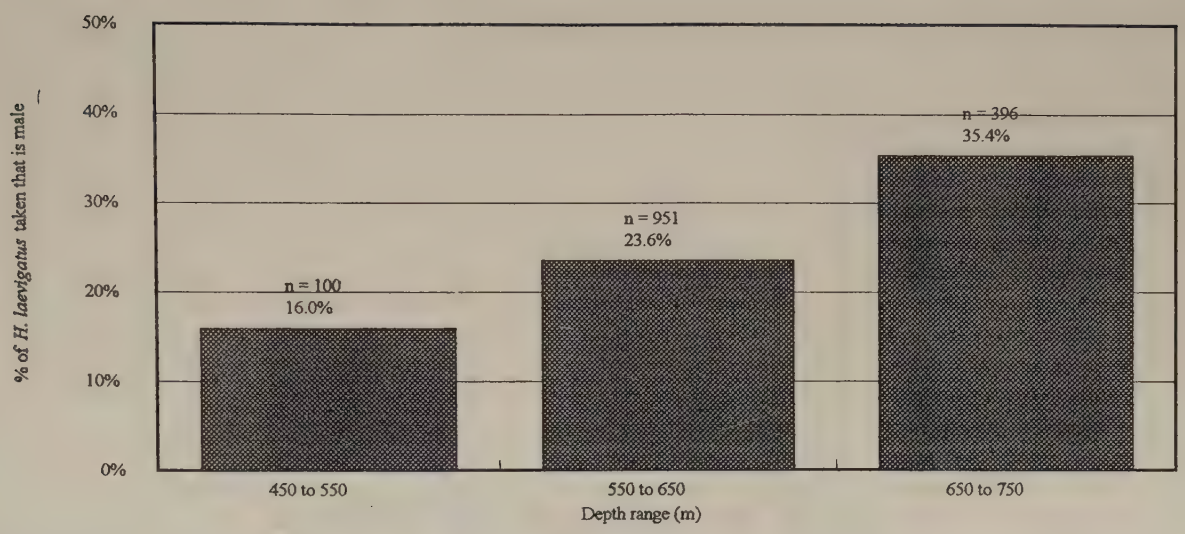


**Figure 20. -** Percent male of total *H. laevigatus* taken by depth over all areas fished by the Marlin II.

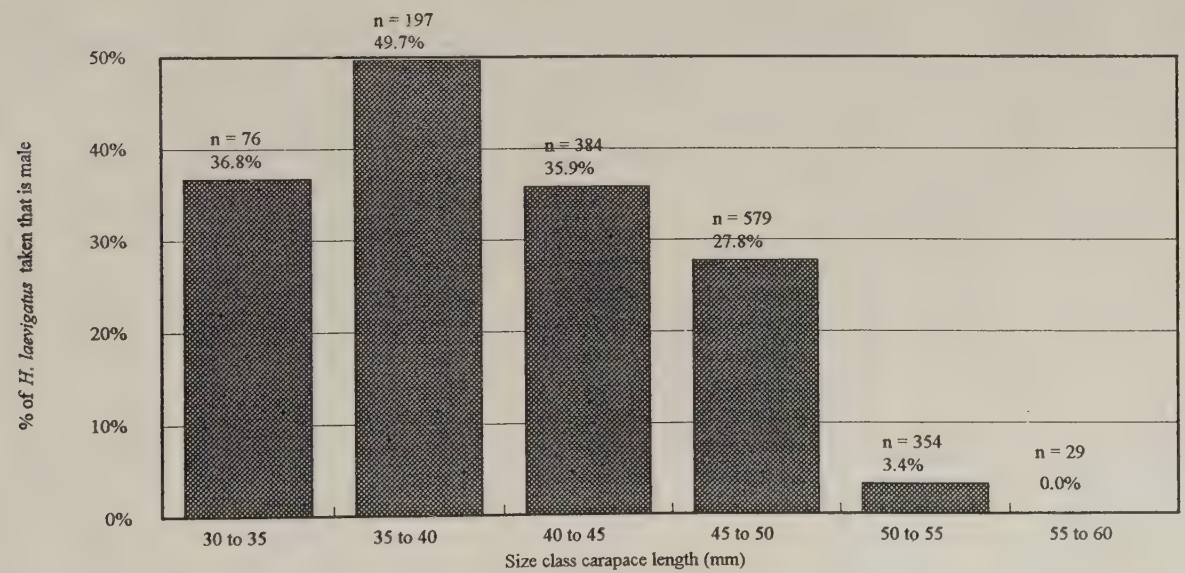


**Figure 21. -** Percent male of *H. laevigatus* taken by size class over all areas fished by the Marlin II.

# APPENDIXES

**Appendix 1.** - A key to the deepwater shrimp of the Pacific Islands (King 1986)

Division CARIDEA

1) - Carapace with strong lateral keels ---------- 2
   - Carapace without strong lateral keels ---------- 3

2) - Prominent hooked dorsal ridge on abdominal segment 3 ---------- *Eugonatonotus crassus* A
   - Low ridge or sharp spines on dorsal edge of abdominal segments ---------- *Heterocarpus*

3) - Rostrum broad; 2 ventral teeth ---------- *Periclimenes* sp. B
   - Rostrum narrow; many ventral teeth ---------- 4

4) - Rostrum with many (>40) fine dorsal teeth ---------- *Parapandalus serratifrons* C
   - Rostrum with few (<40) coarse dorsal teeth ---------- *Plesionika*

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Genus *Heterocarpus*

1) - Abdominal segments with median dorsal spines ---------- 2
   - Abdominal segments 3 with median dorsal ridge ---------- 4

2) - Dorsal spines on segments 3 and 4 ---------- 3
   - Dorsal spines on segments 3, 4 and 5 ---------- *dorsalis* D

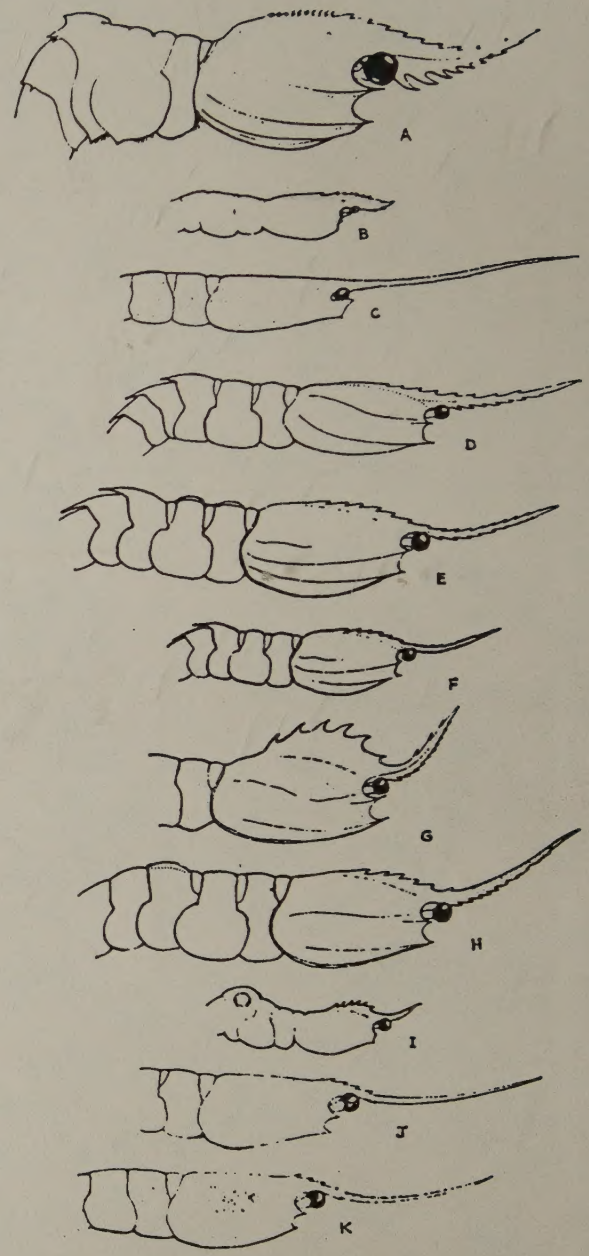
3) - Dorsal spines of equal length; dorsal ridges on segments 1 and 2 ---------- *sibogae* E
   - Dorsal spine on 4 smaller than 3; no dorsal ridges on segments 1 and 2 ------ *ensifer* F

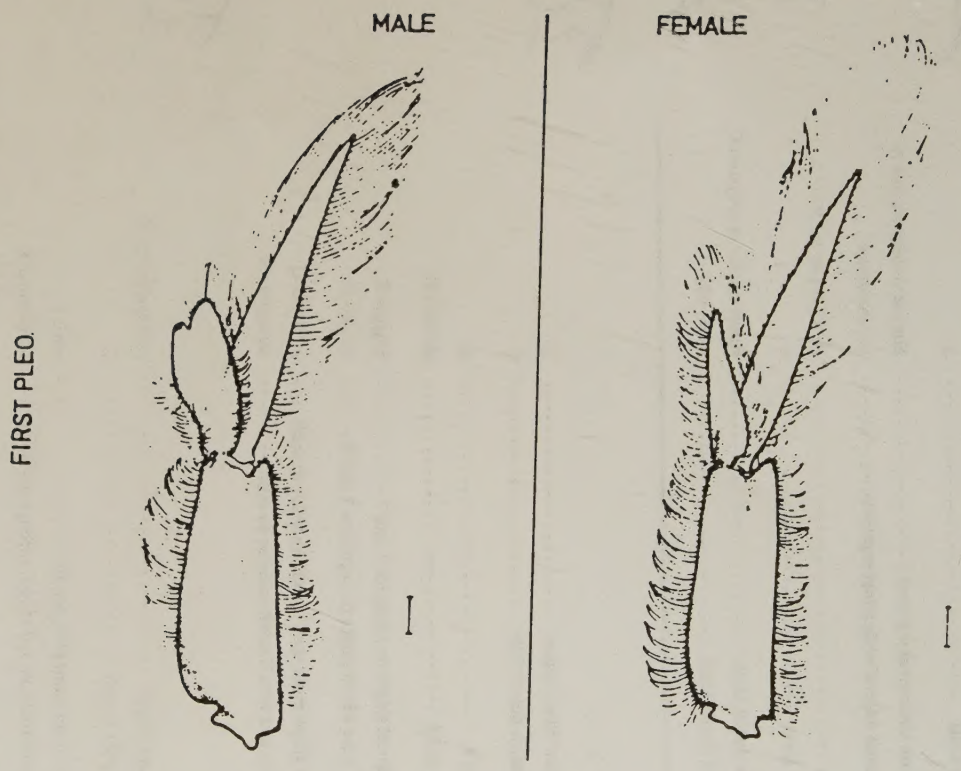
4) - Post rostral teeth on high dorsal ridge; more than 2 teeth anterior to orbit --- *gibbosus* G
   - No high dorsal ridge on carapace; less than 2 teeth anterior to orbit -------- *laevigatus* H

Genus *Plesionika*

1) - Rostrum length less than carapace length ---------- *rostricrescentis* I
   - Rostrum length more than carapace length ---------- 2

2) - Dorsal rostral teeth only at base of rostrum; pink colour ---------- *ensis* J
   - Dorsal rostral teeth along length of rostrum; red stripes through abdomen --- *longirostris* K






**Appendix 2.** - First pleopod of *Heterocarpus sibogae* from King and Moffit (1984). Vertical scale indicates 1 mm. The first pleopod, showing the shape of the male (left) and the female (right) endopod. Pleopoda from specimens 26 mm in carapace length.